Light microscopic dataset of angiosperm pollen diversity from Sirmaur district, Himachal Pradesh (India)

Conjunto de datos de microscopía óptica sobre la diversidad de polen de angiospermas del distrito de Sirmaur, Himachal Pradesh (India)

Kumari Rubal[1]; Devendra K. Srivastava[1*]; Pallvi Kumari[1]; Gauri Dhiman[1]; Kamlesh K. Negi[2]

[1] Department of Botany, Eternal University (EU), Himachal Pradesh – 173101, India.
[2] Department of Botany, Daulat Ram College (DRC), University of Delhi, Old Delhi – 110007, India.
* Corresponding author: <devsrivastv@gmail.com>

Abstract

The present study documents angiosperm pollen diversity from the relatively unexplored high-altitude regions of Sirmaur district, Himachal Pradesh (India), using a light microscopic dataset. It comprises morphometric, viability, and distributional analyses of 70 wild taxa representing 40 families. Herbs dominate the sampled flora, followed by shrubs, trees, and a climber. Considerable variation was observed in pollen size, shape, P/E ratio, symmetry, polarity, aperture types, and exine ornamentation. Seven shape categories were identified, with spheroidal and prolate-spheroidal forms being the most common. Pollen grains were largely radially symmetrical and isopolar, with limited instances of bilateral symmetry and heteropolarity. Eleven aperture types were recorded, predominantly tricolpate. Exine patterns ranged from simple to complex forms. Most pollen fell within a moderate size range, with occasional extremes indicating species-level adaptation. Despite structural diversity, viability remained consistently high.

➤ Ref. bibliográfica: Kumari, R.; Srivastava, D. K.; Kumari, P.; Dhiman, G.; Negi, K. K. 2026. Light microscopic dataset of angiosperm pollen diversity from Sirmaur district, Himachal Pradesh (India). *Lilloa 63* (2): 297-323. doi: https://doi.org/10.30550/j.lil/2409
➤ Recibido: 1 de mayo 2026 – Aceptado: 27 de julio 2026 – Publicado: 9 de septiembre 2026.
➤ URL de la revista: http://lilloa.lillo.org.ar

This dataset provides baseline insights into pollen diversity, supporting taxonomic, ecological, and reproductive interpretations of the regional flora.

Keywords: Aperture types; pollen morphometrics; symmetry; viability.

Resumen

El presente estudio documenta la diversidad de polen de angiospermas en las regiones de gran altitud relativamente inexploradas del distrito de Sirmaur, Himachal Pradesh (India), utilizando un conjunto de datos de microscopía óptica. Comprende análisis morfométricos, de viabilidad y de distribución de 70 taxones silvestres que representan 40 familias. Las hierbas dominan la flora muestreada, seguidas por arbustos, árboles y una planta trepadora. Se observó una variación considerable en el tamaño y la forma del polen, la relación P/E, la simetría, la polaridad, los tipos de aperturas y la ornamentación de la exina. Se identificaron siete categorías de formas, siendo las más comunes las esferoidales y prolato-esferoidales. Los granos de polen presentaron mayoritariamente simetría radial e isopolaridad, con casos limitados de simetría bilateral y heteropolaridad. Se registraron once tipos de aperturas, predominantemente tricolpadas. Los patrones de exina variaron desde formas simples hasta complejas. La mayor parte del polen se situó dentro de un rango de tamaño moderado, con extremos ocasionales que indican adaptación a nivel de especie. A pesar de la diversidad estructural, la viabilidad se mantuvo consistentemente alta. Este conjunto de datos proporciona información básica sobre la diversidad del polen, respaldando interpretaciones taxonómicas, ecológicas y reproductivas de la flora regional.

Palabras clave: Morfometría del polen; simetría; tipos de aperturas; viabilidad.

INTRODUCTION

Palynology plays an important role in interpreting vegetation history, taxonomy, and environmental change (Mudavath *et al.*, 2016; Effiom *et al.*, 2025). Pollen morphology differs significantly among taxa, and show differences in structure, sculpturing, and durable exine ornamentation. These features offer insights into past taxonomic diversity, vegetation, climatic fluctuations, ecological adaptation and adaptive trends (Nair, 1991; Quamar *et al.*, 2017, 2022; Xie, 2024). Advances in microscopic analysis, particularly light microscopy, have improved the resolution of pollen characters and their use in plant classification and phylogenetic interpretation (Tsymbalyuk *et al.*, 2024; Quamar & Stivrins, 2021). Palynomorphological study also assists in resolving taxonomic ambiguities, especially among closely related genera (Javed *et al.*, 2024).

Palynological research is also increasingly used to portray the structure of land flora, ecosystem dynamics, and vegetation change (Effiom *et al.*, 2025). It provides insight into foraging ecology, nectar resource use, and plant-pollinator relationships, identifying preferred plant species for pollinators and nectar-feeding taxa (Gill & Walters, 2022; Dwarka *et al.*, 2025; Lun & Yang, 2025). In addition, pollen data serve as reliable indicators of vegetation composition and bioclimatic gradients (Mudavath *et al.*, 2016; Fyfe *et al.*, 2025). Pollen grains are morphologically distinctive, and owing to their durable nature, they serve as reliable microfossil indicators. Their distribution offers clues to current vegetation composition and aids in calibrating fossil records (Quamar & Stivrins 2021; Ige & Essien, 2021). Beyond basic research, palynological mapping also supports applied studies in aerobiology and allergen forecasting by linking pollen occurrence with seasonal patterns and atmospheric transport (Khaiwal *et al.*, 2021; Parul, 2021; Makra *et al.*, 2024; Pham-Thi & Demoly 2025). It also has applications in emerging fields such as drug delivery, catalysis, and phytoremediation (Ragho, 2020; Wu *et al.*, 2020; Iravani & Varma, 2021).

Although India has seen extensive palynological work, regional investigations remain uneven. In Himachal Pradesh, most studies have focused on restricted localities, leaving substantial areas unexplored. Notable contributions are region-specific and include the works of Kaur *et al.* (2019) from Kangra, Trivedi *et al.* (2023) from Shimla, and earlier studies by Saxena & Bhattacharyya (1986), and Sarkar & Prasad (2002) from Sirmaur. Recent research includes studies by Sharma *et al.* (2021) and Kumar *et al.* (2022), covering broader regions of the state. In addition to these, a few investigations have explored melissopalynology, such as those by Devi & Mattu (2017) from Kangra, Singh *et al.* (2017) from Shimla, and Saklani *et al.* (2018) from Hamirpur, Saklani & Mattu *et al.* (2020) from Kangra Hills, with Jamwal (2021) examining samples from various parts of Himachal Pradesh. In light of the above limited regional studies, this study aims to provides a light microscopic dataset of angiosperm pollen diversity from the relatively unexplored regions of District Sirmaur (Himachal Pradesh, India), contributing to a broader understanding of regional vegetation and its taxonomic representation through pollen analysis.

MATERIALS AND METHODS

Plant materials for the present study were collected from wild populations growing in natural habitats of Sirmaur District, Himachal Pradesh. Sampling was carried out from 18 population sites, namely, Chabahan, Nahan, Sarahan, Baru-Sahib, Chhapang, Lana Macher, Mangarh, Narag, Neri Nawan, Wasni, Paonta-Sahib, Dimber, Koti-Pahog, Rajgarh, Sangrah, Gandhuri, Thanga and Baunal (Fig. 1, Table 1).

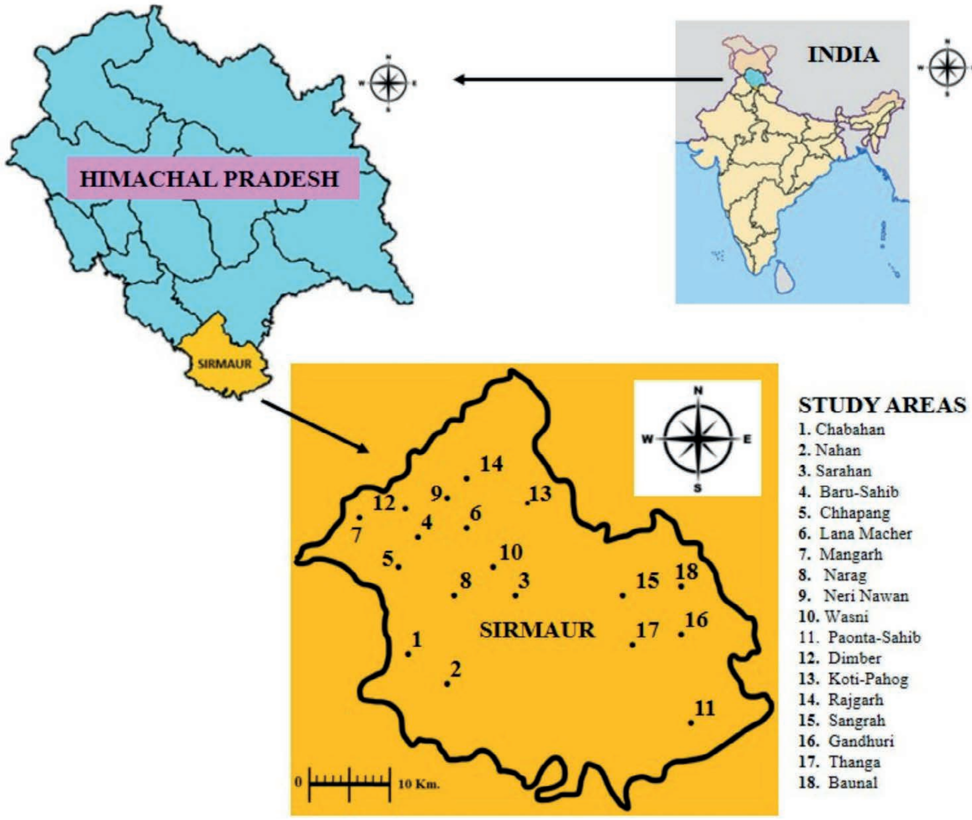

Fig. 1. Map of the study area, showing the plant population (collection) sites.

Fig. 1. Mapa del área de estudio donde se muestran los sitios de recolección de las poblaciones vegetales.

These sites fall under five major study areas, i.e. Nahan, Pachhad, Paonta-Sahib, Rajgarh, and Sangrah. Collections were made during the years 2022 to 2025. The plants were identified by consulting national and regional floras [e.g. Flora of British India (Hooker, 1875-1897), Flora of Sirmaur (Kaur & Sharma, 2004), Flora of Himachal Pradesh (Chowdhery & Wadhwa, 1984a, 1984b)], and taxa were confirmed with authentic specimens lodged in the herbarium of Punjabi University (Patiala) and Botanical Survey of India (Dehradun), and digital herbaria of Indian Institute of Integrative Medicine, Jammu (The Janaki Ammal Herbarium). Voucher (herbarium) specimens of all the studied plants are deposited at the department of Botany, Eternal University (H.P.).

For the pollen study, mature floral buds (/ flower anthers) were fixed in Carnoy's fixative (6:3:1= ethanol: chloroform: glacial acetic acid, v/v) for 24 h and preserved in 70% ethanol at 4 °C. Anthers from the collected floral buds were crushed on slide to view the pollens. Approximately 150–200 pollen grains per taxon were examined for detailed morphological observations. The pollen samples were stained using 1.5% Safranin or, in some cases, 0.1% Toluidine Blue and mounted in glycerine jelly, primarily for observing fresh pollen characteristics.

Table 1. Study area and GPS coordinates of the population sampling sites for material collection.

Tabla 1. Área de estudio y coordenadas GPS de los sitios poblacionales utilizados para la recolección del material.

S.N.	Study Area		GPS Coordinates**	
	Local Identifier	Population Sites*	N-Latitude	E-Longitude
1.	Nahan	CHA: Chabahan (1,500 m)	30° 35′ 45.6′′	77° 17′ 16.8′′
		NAH: Nahan (1,430 m)	30° 33′ 21.6′′	77° 17′ 52.8′′
		SAR: Sarahan (1,550 m)	30° 43′ 22.8′′	77° 10′ 58.8′′
2.	Pachhad	BS: Baru Sarera (970 m)	30° 45′ 10.8′′	77° 17′ 31.2′′
		CHH: Chhapang (850 m)	30° 44′ 16.8′′	77° 18′ 46.8′′
		LM: Lana Macher (850 m)	30° 45′ 25.2′′	77° 18′ 7.2′′
		MAN: Mangarh (1,552 m)	30° 45′ 14.4′′	77° 14′ 56.4′′
		NAR: Narag (980 m)	30° 49′ 1.2′′	77° 11′ 13.2′′
		NN: Neri Nawan (1,030 m)	30° 45′ 7.2′′	77° 17′ 24′′
		WAS: Wasni (1,552 m)	30° 47′ 45.6′′	77° 13′ 44.4′′
3.	Paonta-Sahib	PS: Paonta Sahib (508 m)	30° 27′ 7.2′′	77° 35′ 20.4′′
4.	Rajgarh	DIM: Dimber (1,520 m)	30° 47′ 38.4′′	77° 17′ 52.8′′
		KP: Koti Pahog (1,470 m)	30° 47′ 38.4′′	77° 17′ 52.8′′
		RAJ: Rajgarh (1,720 m)	30° 50′ 56.4′′	77° 17′ 45.6′′
5.	Sangrah	SAN: Sangrah (2, 200 m)	30° 43′ 44.4′′	77° 26′ 42′′
		GAN: Gandhuri (1,500 m)	30° 48′ 10.8′′	77° 27′ 0′′
		THA: Thanga (1,520 m)	30° 48′ 25.2′′	77° 26′ 31.2′′
		BAU: Baunal (1,450 m)	30° 39′ 7.2′′	77° 26′ 20.4′′

** Names of the population sites as per the Google Identifier GPS, **DMS : Degrees, Minutes, and Seconds.

* Nombres de los sitios de población según el identificador GPS de Google, **DMS: grados, minutos y segundos.

Detailed morphological analysis was carried out using the acetolysis method following Erdtman (1960), with procedures adapted from Halbritter *et al*. (2018). The classification of pollen types was done according to the system proposed by Erdtman (1952). For terminology and descriptive standards, references were made to Kremp (1965) and Halbritter *et al*. (2018).

A measurement of the diameter of viable pollens was done on pre-calibrated compound light microscope using Ocular micrometre. A glycerol-acetocarmine (1:1) staining method of Mark (1954) was used to assess the pollen viability. The pollen viability percentage were estimated using the following formula: Photomicrographs were taken with the help of COSLAB digital light-microscope (HL-10 DIGI / 10052-10053 with mounted CMOS camera) at 450× magnification, with 10x field of view.

RESULTS

The results of the present study are organized under the following sub-heads: Floristic representation and life-forms of the studied taxa, Pollen symmetry and polarity, Apertural configurations, Exine ornamentation patterns, Morphometric polar (P) and equatorial (E) dimensions, P/E ratio and derived pollen shapes, Apertural dimensions and exine thickness, and Pollen viability across the studied species.

Table 2. Studied taxa, family, life span, distribution, habit and flowering months.

Tabla 2. Taxones estudiados, familia, duración de vida, distribución, hábito y meses de floración.

S.N.	Taxa	Family	Fig.	LS	Dist.	H	Flowering Months
1	*Justicia adhatoda* L.	Acanthaceae	4A-B	*P*	LM	*S*	Feb-June, Oct-Nov
2	*Cleretum bellideliform* Burm. F.	Aizoaceae	4C-D	*A*	NN	*H*	Feb-May
3	*Hymenocallis littoralis* Jacq.	Amaryllidaceae	4E-F	*P*	BS	*H*	Feb-May
4	*Amaryllis belladonna* L.	Amaryllidaceae	4G-H	*P*	SAR	*H*	March-Oct
5	*Foeniculum vulgare* Mill.	Apiaceae	4I-J	*P*	BS	*H*	March-Sept
6	*Carissa spinarum* L.	Apocynaceae	4K-L	*B*	LM	*S*	March-May
7	*Holarrhena pubescens* Wall. ex G. Don.	Apocynaceae	4M-N	*B*	THA	*S*	March-June
8	*Nerium oleander* L.	Apocynaceae	4O-P	*P*	SAN	*T*	Feb-Sept
9	*Achillea millefolium* L.	Asteraceae	4Q-R	*P*	BS	*H*	Feb-Oct
10	*Bellis perennis* L.	Asteraceae	4S-T	*P*	LM	*H*	Feb-Nov
11	*Calendula officinalis* L.	Asteraceae	5A-B	*A*	LM	*H*	March-May
12	*Chrysanthemum multiflora* L.	Asteraceae	5C-D	*P*	GAN	*H*	Nov.-Dec
13	*Coreopsis lanceolata* L.	Asteraceae	5E-F	*P*	DIM	*H*	August-Sept
14	*Echinops echinatus* Roxb.	Asteraceae	5G-H	*A*	RAJ	*H*	Sept-Nov
15	*Emilia sonchifolia* L.	Asteraceae	5I-J	*A*	NAR	*H*	March-Oct
16	*Gazania rigens* L.	Asteraceae	5K-L	*P*	NAR	*H*	March-Aug
17	*Glebionis segetum* L.	Asteraceae	5M-N	*A*	LM	*H*	Feb-Dec
18	*Hypochaeris sonchoides* Kunth.	Asteraceae	5O-P	*P*	BS	*H*	March-May, Sept-Nov
19	*Jacobaea vulgaris* L.	Asteraceae	5Q-R	*A*	LM	*H*	July-Nov
20	*Berberis aristata* DC.	Berberidaceae	5S-T	*A*	RAJ	*S*	March-July
21	*Jacaranda mimosifolia* D. Don.	Bignoniaceae	6A-B	*P*	BS	*T*	March-July
22	*Iberis sempervirens* L.	Brassicaceae	6C-D	*P*	BS	*S*	March-June
23	*Campanula portenschlagiana* Schult.	Campanulaceae	6E-F	*P*	CHH	*H*	June-July
24	*Campanula macrostyla* Boiss & Helder.	Campanulaceae	6G-H	*P*	KP	*H*	June-Oct
25	*Canna indica* L.	Cannaceae	6I-J	*P*	BS	*H*	April-Nov
26	*Dianthus chinensis* L.	Caryophyllaceae	6K-L	*P*	BS	*H*	March-Aug
27	*Commellina cyanea* R. Br	Commelinaceae	6M-N	*P*	RAJ	*H*	March-June
28	*Convolvulus arvensis* L.	Convolvulaceae	6O-P	*P*	BS	*H*	Feb-Oct
29	*Ipomoea hederaceae* Jacq.	Convolvulaceae	6Q-R	*A*	MAN	*H*	June-Dec
30	*Luffa acutangular* L.	Cucurbitaceae	6S-T	*P*	BS	*H*	March-Sept
31	*Jatropha integerrima* Jacq.	Euphorbiaceae	7A-B	*P*	BS	*S*	July-Dec
32	*Biancaea decapetala* Roth.	Fabaceae	7C-D	*A*	CHA	*S*	March-July
33	*Bauhinia Variegata* L.	Fabaceae	7E-F	*A*	NAR	*T*	Marh-June
34	*Cullen corylifolium* L.	Fabaceae	7G-H	*A*	RAJ	*H*	Sept-Dec
35	*Desmodium triflorum* L.	Fabaceae	7I-J	*P*	RAJ	*H*	July-Nov
36	*Indigofera tinctoria* L.	Fabaceae	7K-L	*A*	BS	*H*	Jan-April & Nov-Dec
37	*Leucaena leucocephala* Benth.	Fabaceae	7M-N	*P*	LM	*T*	May-Oct
38	*Medicago lupina* L.	Fabaceae	7O-P	*A*	SAR	*H*	Feb-April
39	*Gentiana kurroo* Royle	Gentianaceae	7Q-R	*P*	BS	*H*	March-Sept
40	*Hydrangea arborescens* L.	Hydrangeaceae	7S-T	*P*	BAU	*S*	April-Oct
41	*Hypericum triquetrifolium* Turra	Hypericaceae	8A-B	*A*	BS	*S*	Feb-Oct
42	*Clerodendrum inerme* L.	Lamiaceae	8C-D	*A*	BS	*T*	April-Oct
43	*Ocimum basilicum* L.	Lamiaceae	8E-F	*A*	PS	*H*	June-Sept
44	*Lagersroemia indica* L.	Lythraceae	8G-H	*A*	BS	*S*	March-May
45	*Lagerstroemia speciosa* L.	Lythraceae	8I-J	*A*	BS	*S*	March-Nov
46	*Magnolia champaca* L.	Magnoliacea	8K-L	*P*	NN	*T*	March-Sept
47	*Abelmoschus esculentus* L.	Malvaceae	8M-N	*A*	BS	*H*	June-July
48	*Melia azedarach* L.	Meliaceae	8O-P	*P*	PS	*T*	March-Dec
49	*Callistemon citrinus* Curtis	Myrtaceae	8Q-R	*P*	BS	*S*	March-May
50	*Mirabilis jalapa* L.	Nyctaginaceae	8S-T	*P*	BS	*H*	Feb-July

Table 2. Studied taxa, family, life span, distribution, habit and flowering months.

Tabla 2. Taxones estudiados, familia, duración de vida, distribución, hábito y meses de floración.

S.N.	Taxa	Family	Fig.	LS	Dist.	H	Flowering Months
51	*Jasminium nudiflorum* Lindl.	Oleaceae	9A-B	*P*	WAS	*S*	Jan-Sept
52	*Ligustrum japonicum* Thunb.	Oleaceae	9C-D	*P*	BS	*H*	March-Sept
53	*Nyctanthes arbor* L.	Oleaceae	9E-F	*P*	NAH	*H*	April-Nov
54	*Earina autumnalis* G. Forst.	Orchidaceae	9G-H	*P*	BS	*H*	April-Aug
55	*Argemone mexicana* L.	Papaveraceae	9I-J	*A*	RAJ	*H*	Feb-Nov
56	*Eschscholzia californica* Cham.	Papaveraceae	9K-L	*P*	BS	*H*	Feb-April
57	*Antirrhinum majus* L.	Plantaginaceae	9M-N	*A*	BAU	*H*	April-Sept
58	*Coix lacryma-jobi* L.	Poaceae	9O-P	*A*	BS	*H*	Jan-April
59	*Grevillea robusta* A. Cunn. ex R.Br.	Proteaceae	9Q-R	*A*	BS	*T*	April-June
60	*Clematis apiifolia* DC.	Ranunculaceae	9S-T	*P*	CHH	*C*	July-Sept
61	*Fragaria chiloensis* Mill.	Rosaceae	10A-B	*P*	BS	*H*	March-June & Nov-Dec
62	*Murraya koenigii* L.	Rutaceae	10C-D	*P*	MAN	*S*	April-July
63	*Myoporum oppositifolium* R. Br.	Scrophulariaceae	10E-F	*P*	RAJ	*S*	March-Nov
64	*Datura quercifolia* Kunth.	Solanaceae	10G-H	*A*	CHA	*H*	May-Nov
65	*Aloysia virgata* Juss.	Verbenaceae	10I-J	*P*	BS	*S*	March-Oct
66	*Duranta eracta* L.	Verbenaceae	10K-L	*P*	BS	*S*	March-Sept
67	*Lantana camara* L.	Verbenaceae	10M-N	*P*	RAJ	*S*	Jan-Dec
68	*Verbena officinalis* L.	Verbenaceae	10O-P	*A*	DIM	*H*	Feb-June
69	*Alpinia zerumbet* Pers.	Zingiberaceae	10Q-R	*P*	BS	*H*	Jan-June
70	*Curcuma aromatica* L.	Zingiberaceae	10S-T	*P*	BS	*H*	May-June

LS: Life span (*A* = Annual, *B* = Biennial, *P* = Perennial); **Dist.**: Distribution (by population sites); **H**: Growth habit (*C* = Climbers, *H* = Herbs, *S* = Shrubs, *T* = Trees).

LS: Ciclo de vida (*A* = Anual, *B* = Bienal, *P* = Perenne); **Dist.**: Distribución (por sitios de población); **H**: Hábito de crecimiento (*C* = Trepadoras, *H* = Hierbas, *S* = Arbustos, *T* = Árboles).

Details of the studied taxa, including their life span, distribution, habit, and flowering period, are presented in Table 2. Comprehensive pollen morphological data covering shape, P × E dimensions, P/E ratio, polarity, symmetry, aperture types, ornamentation, colpus dimensions, exine thickness, and pollen viability are summarized in Table 3. The diversity and distribution of life-history traits and pollen characteristics are illustrated using pie charts in Fig. 2, while palynomorphometric analyses are presented in Fig. 3. Representative pollen microphotographs of the studied taxa are provided in Figs. 4-10.

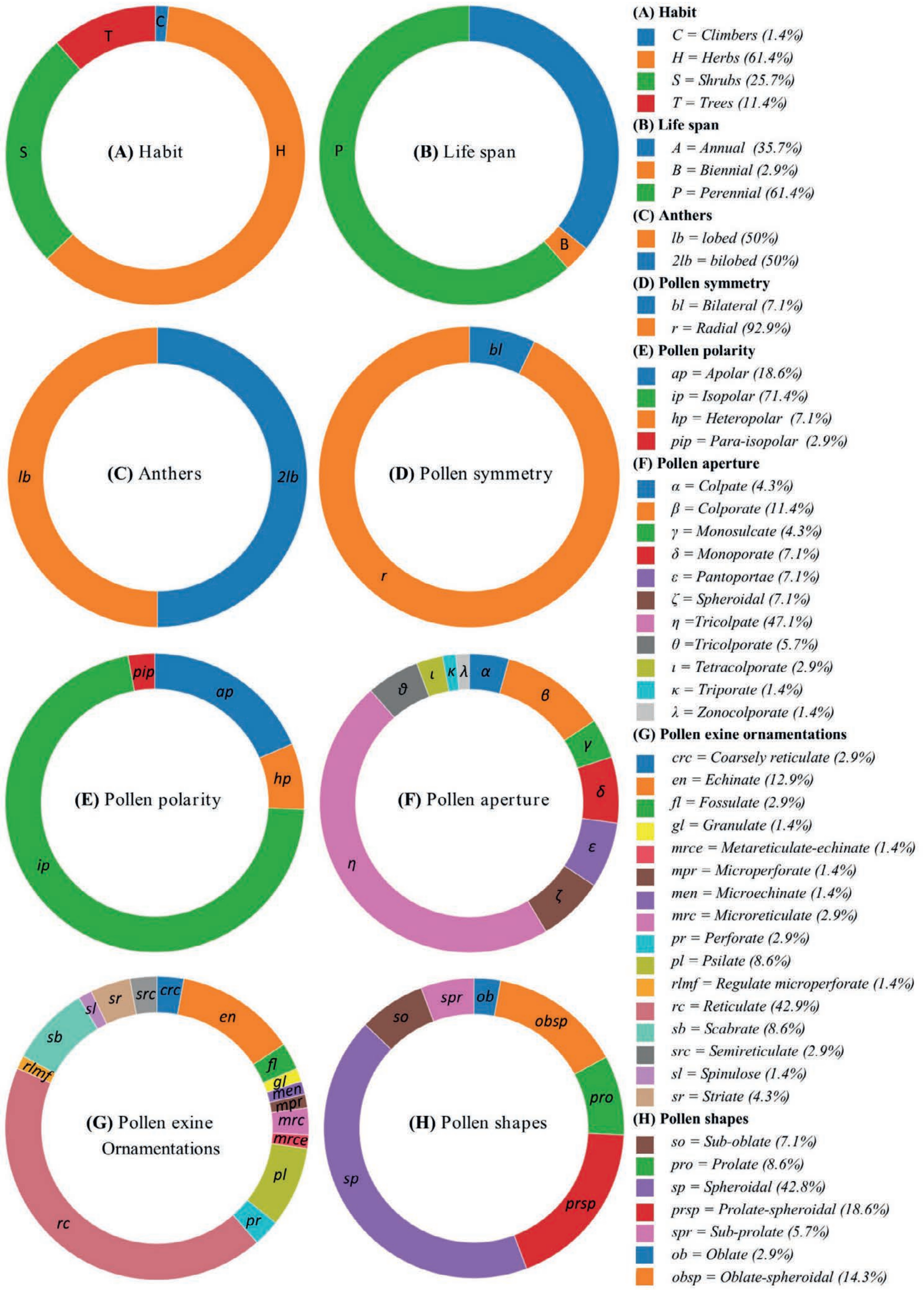

Fig 2. Pie charts showing distribution of life-history traits and pollen characters among the studied taxa: A) Habit. B) Life span. C) Anther type. D) Pollen Symmetry. E) Pollen polarity. F) Pollen aperture types. G) Pollen exine ornamentations. H) Pollen shapes observed in the studied taxa.

Fig. 2. Gráficos circulares que muestran la distribución de los rasgos de historia de vida y los caracteres polínicos entre los taxones estudiados: A) Hábito. B) Duración de vida. C) Tipo de antera. D) Simetría del polen. E) Polaridad del polen. F) Tipos de aperturas del polen. G) Ornamentaciones de la exina del polen. H) Formas del polen observadas en los taxones estudiados.

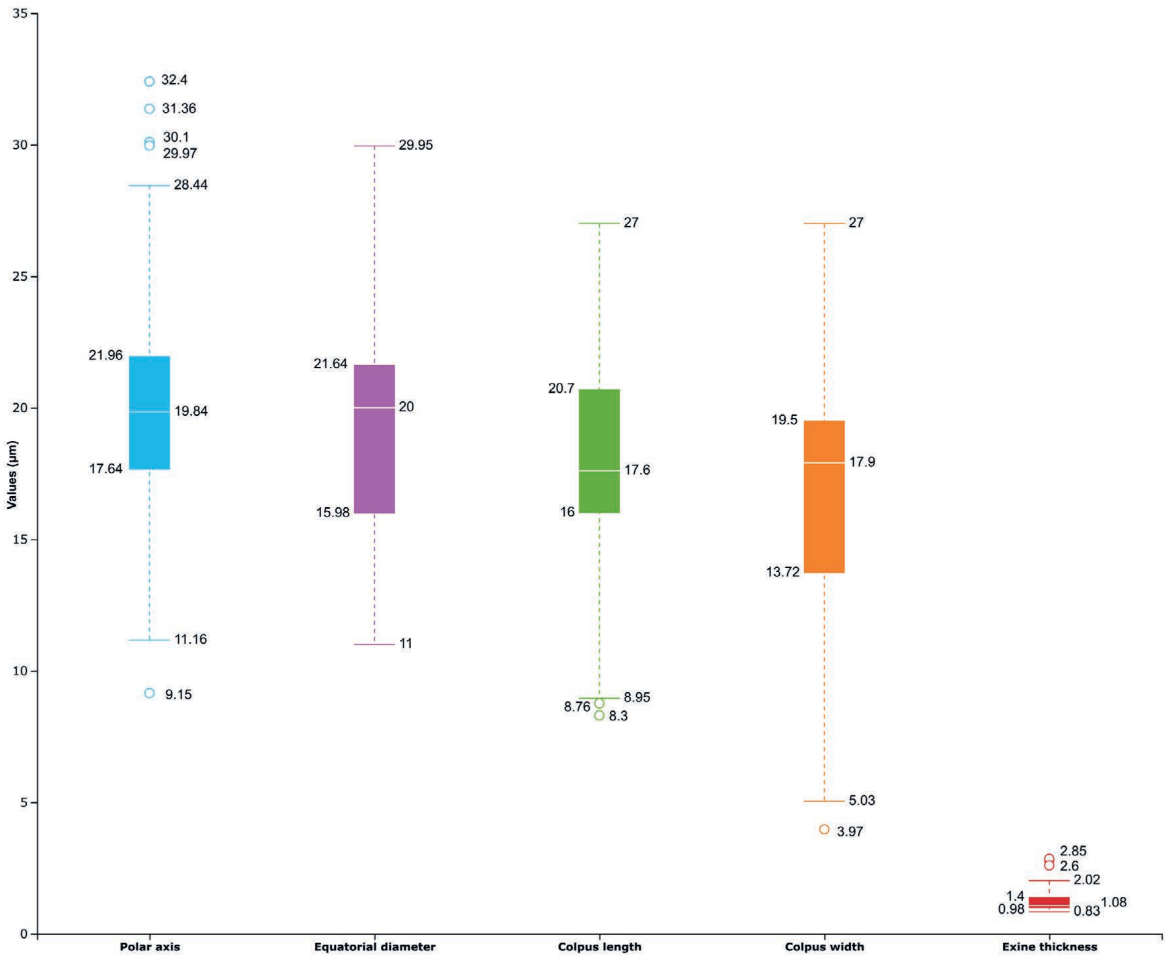

Fig. 3. Box plots for pollen morphometric characters among the studied taxa.

Fig. 3. Diagramas de caja para los caracteres morfométricos del polen entre los taxones estudiados.

Floristic representation and life-forms of the studied taxa

The present study was conducted on 70 angiosperm taxa belonging to 40 families, namely, Acanthaceae, Aizoaceae, Amaryllidaceae, Apiaceae, Apocynaceae, Asteraceae, Berberidaceae, Bignoniaceae, Brassicaceae, Campanulaceae, Cannaceae, Caryophyllaceae, Commelinaceae, Convolvulaceae, Cucurbitaceae, Euphorbiaceae, Fabaceae, Gentianaceae, Hydrangeaceae, Hypericaceae, Lamiaceae, Lythraceae, Magnoliacea, Malvaceae, Meliaceae, Myrtaceae, Nyctaginaceae, Oleaceae, Orchidaceae, Papaveraceae, Plantaginaceae, Poaceae, Proteaceae, Ranunculaceae, Rosaceae, Rutaceae, Scrophulariaceae, Solanaceae, Verbenaceae, and Zingiberaceae, representing a diverse taxonomic representation of the flora of district Sirmaur of Himachal Pradesh (Table 2). The dataset includes a range of life forms, with approx. 61.4% herbs (H), followed by 25.7% shrubs (S), 11.4% trees (T), and a single (*Clematis apiifolia* DC.) climber (C) species (Fig 2A).

Table 3. Pollen shape, P × E dimensions, P/E ratio, polarity (π), symmetry (Sym.), aperture (Ap.), ornamentations (Ω), colpus length (CL), colpus width (CW), exine thickness (ET) and pollen viability (PV) % in the studied taxa.

Tabla 3. Forma del polen, dimensiones P × E, relación P/E, polaridad (π), simetría (Sym.), apertura (Ap.), ornamentaciones (Ω), longitud del colpo (CL), ancho del colpo (CW), grosor de la exina (ET) y porcentaje de viabilidad del polen (PV) en los taxones estudiados.

S.N.	Taxa	PS	P × E (μm)	P/E	Colpi	π	Sym.	Ap.	Ω	CL (μm)	CW (μm)	ET (μm)	PV
1.	*J. adhatoda*	*spr*	31.36 × 24.50	1.28	1	*ip*	r	δ	*rc*	23.50	05.60	0.98	100
2.	*C. bellidiliform*	*obsp*	18.10 × 19.90	0.91	1	*ap*	r	δ	*crc*	19.70	12.23	0.83	93
3.	*H. littoralis*	*obsp*	21.80 × 24.50	0.89	1	*hp*	r	ζ	*rc*	20.40	19.90	1.32	94
4.	*A.belladonna*	*sp*	30.10 × 29.50	1.02	1	*ip*	r	γ	*rc*	22.32	07.90	0.99	100
5.	*F. vulgare*	*pro*	32.40 × 20.00	1.64	3	*ip*	r	η	*rc*	22.04	03.97	1.00	84
6.	*C. spinarum*	*sp*	22.20 × 21.30	1.04	3	*ip*	r	η	*rc*	17.00	18.67	1.20	90
7.	*H. pubescens*	*sp*	21.56 × 22.00	0.98	1	*ap*	r	η	*pl*	16.72	18.06	0.99	100
8.	*N. oleander*	*sp*	19.40 × 20.00	0.97	3	*ap*	r	η	*pl*	16.50	18.00	1.38	87
9.	*millefolium*	*prsp*	24.20 × 22.00	1.10	3	*ip*	r	η	*en*	23.32	21.60	0.98	100
10.	*B. perennis*	*prsp*	22.40 × 20.00	1.12	3	*ip*	r	η	*en*	22.00	19.67	1.83	90
11.	*C. officinalis*	*prsp*	21.80 × 20.00	1.09	3	*ip*	r	η	*en*	20.00	18.09	1.45	100
12.	*C. multiflora*	*prsp*	26.64 × 24.00	1.11	3	*ip*	r	η	*en*	24.60	22.00	1.70	93
13.	*C. lanceolata*	*prsp*	15.26 × 14.00	1.09	3	*ip*	r	η	*en*	13.87	12.00	1.16	97
14.	*E. echinatus*	*so*	20.00 × 15.80	0.79	1	*ap*	bl	α	*sb*	16.00	09.54	1.20	100
15.	*E. sonchifolia*	*ob**	11.80 × 20.00	0.59	3	*ip*	r	η	*sb*	08.76	18.00	0.97	96
16.	*G. rigens*	*sp*	21.00 × 20.00	1.05	4	*ip*	r	η	*en*	19.23	19.00	0.98	100
17.	*G. segetum*	*obsp*	19.17 × 21.30	0.90	3	*ip*	r	η	*rc*	16.78	18.09	1.00	95
18.	*H. sonchoides*	*obsp*	13.62 × 15.30	0.89	3	*hp*	r	ζ	*rc*	13.00	12.98	1.20	100
19.	*J. vulgaris*	*sp*	19.89 × 15.30	1.30	3	*ip*	r	η	*rc*	17.89	14.00	1.00	100
20.	*A. aristata*	*sp*	19.40 × 20.00	0.97	1	*ip*	r	α	*sb*	16.80	19.00	0.96	100
21.	*J. mimosifolia*	*prsp*	26.56 × 23.50	1.13	3	*ip*	r	θ	*sr*	25.70	22.23	0.99	100
22.	*I. sempervirens*	*sp*	19.40 × 20.00	0.97	3	*ip*	r	η	*rc*	17.60	20.00	2.80	97
23.	*C. portenschla-giana*	*sp*	18.72 × 18.00	1.04	3	*ip*	r	κ	*mrc*	17.45	16.00	1.2	100
24.	*C. macrostyla*	*sp*	26.00 × 25.00	1.04	1	*hp*	r	ζ	*rc*	24.79	24.00	0.98	95
25.	*C. indica*	*sp*	20.80 × 20.00	1.04	1	*ip*	r	α	*sb*	19.00	18.80	1.00	100
26.	*D. chinensis*	*sp*	23.28 × 24.00	0.97	5	*ip*	r	ε	*mpr*	21.90	22.00	1.35	97
27.	*C. cyanea*	*sp*	20.00 × 19.42	1.03	1	*pip*	bl	γ	*en*	18.00	18.60	0.95	99
28.	*C. arvensis*	*obsp*	27.80 × 29.95	0.92	3	*ip*	r	η	*men*	25.60	27.00	0.96	99
29.	*I. hederaceae*	*sp*	15.60 × 15.00	1.04	1	*ap*	r	ε	*mrce*	14.30	14.00	0.92	94
30.	*L. acutangula*	*sp*	19.60 × 20.00	0.98	1	*ip*	r	β	*rc*	18.90	19.00	1.00	100
31.	*J. integerrima*	*sp*	12.67 × 12.30	1.03	1	*ap*	r	η	*rc*	11.78	11.00	0.95	100
32.	*B. decapetala*	*sp*	21.10 × 21.75	0.97	3	*ap*	r	η	*rc*	20.00	20.05	0.94	98
33.	*B. variegata*	*prsp*	21.60 × 20.00	1.08	3	*ip*	r	θ	*sr*	20.32	19.00	1.20	92
34.	*C. corylifolium*	*sp*	15.30 × 15.00	1.02	3	*ip*	r	η	*rc*	14.30	13.00	0.97	100
35.	*D. triflorum*	*so*	17.64 × 21.00	0.84	3	*ip*	r	η	*rc*	16.30	20.00	0.89	91
36.	*I. tinctoria*	*sp*	26.00 × 25.00	1.04	3	*ip*	r	η	*rc*	25.00	23.70	0.89	93
37.	*L. leucocephala*	*spr*	23.10 × 19.10	1.21	3	*ip*	r	η	*pl*	22.00	18.20	0.91	92
38.	*M. lupina*	*pro*	19.22 × 12.40	1.55	3	*ap*	r	η	*rc*	16.90	11.50	1.20	100
39.	*G. kurroo*	*pro*	17.91 × 12.70	1.41	3	*ap*	r	η	*fl*	15.63	11.20	1.35	100
40.	*H. arborescens*	*pro*	16.83 × 11.00	1.53	3	*ap*	r	η	*fl*	14.62	10.85	1.29	85
41.	*H. triquetrifo-lium*	*spr*	17.55 × 15.00	1.17	3	*ap*	r	k	*pr*	16.00	13.70	0.97	100
42.	*C. inerme*	*prsp*	26.10 × 23.50	1.11	3	*ip*	r	η	*gl*	25.00	22.46	0.95	92
43.	*O. basilicum*	*so*	16.80 × 21.80	0.77	1	*ip*	r	β	*rc*	15.00	20.00	1.00	100
44.	*L. indica*	*prsp*	16.35 × 15.00	1.09	8	*ip*	r	λ	*sb*	15.30	14.00	1.90	100
45.	*L. speciosa*	*prsp*	19.78 ×17.50	1.13	3	*ip*	r	η	*rc*	17.50	16.00	2.85	100
46.	*M. champaca*	*obsp*	18.40 × 20.00	0.92	1	*ip*	r	β	*rc*	17.20	15.00	0.99	99
47.	*A. esculentus*	*sp*	17.15 × 17.50	0.98	1	*ip*	r	ε	*en*	15.00	15.10	1.25	100
48.	*M. azedarach*	*prsp*	21.80 × 20.00	1.09	1	*ip*	r	ι	*mrc*	20.00	18.50	2.60	100

Table 3. Pollen shape, P × E dimensions, P/E ratio, polarity (π), symmetry (Sym.), aperture (Ap.), ornamentations (Ω), colpus length (CL), colpus width (CW), exine thickness (ET) and pollen viability (PV) % in the studied taxa.

Tabla 3. Forma del polen, dimensiones P × E, relación P/E, polaridad (π), simetría (Sym.), apertura (Ap.), ornamentaciones (Ω), longitud del colpo (CL), ancho del colpo (CW), grosor de la exina (ET) y porcentaje de viabilidad del polen (PV) en los taxones estudiados.

S.N.	Taxa	PS	P × E (μm)	P/E	Colpi	Π	Sym.	Ap.	Ω	CL (μm)	CW (μm)	ET (μm)	PV
49.	*C. citrinus*	*prsp*	21.90 × 20.10	1.09	3	*ip*	r	ι	*pl*	21.00	18.02	1.75	94
50.	*M. jalapa*	*sp*	21.15 × 20.10	1.05	1	*ap*	r	ε	*sl*	20.80	19.00	1.50	93
51.	*J. nudiflorum*	*sp*	20.48 × 19.50	1.05	3	*ip*	r	β	*rc*	19.00	17.40	1.73	100
52.	*L. japonicum*	*sp*	15.10 × 14.80	1.02	3	*ip*	r	β	*rc*	15.00	13.76	0.99	100
53.	*N. arbor*	*spr*	23.50 × 19.40	1.21	3	*ip*	r	k	*rc*	21.56	18.60	1.25	100
54.	*E. autumnalis*	*ob*	09.15 × 15.00	0.61	1	*pip*	bl	γ	*en*	08.30	13.70	0.93	100
55.	*A. mexicana*	*sp*	18.72 × 18.00	1.04	3	*ip*	r	η	*rc*	17.00	16.00	1.45	100
56.	*E. californica*	*obsp*	18.72 × 20.80	0.90	1	*ap*	r	δ	*crc*	17.60	17.00	0.98	100
57.	*A. majus*	*sp*	21.00 × 22.00	1.05	3	*ip*	r	η	*rc*	19.30	20.00	1.00	100
58.	*C. lacryma-jobi*	*sp*	18.13 × 18.50	0.98	1	*ip*	r	δ	*pl*	16.00	16.70	2.60	93
59.	*G. robusta*	*pro**	25.38 × 18.00	1.41	3	*ip*	r	η	*sb*	23.70	15.00	0.99	92
60.	*C. apiifolia*	*sp*	20.80 × 20.00	1.04	3	*ip*	r	β	*rc*	18.00	17.80	1.75	99
61.	*F. chiloensis*	*pro*	21.98 × 14.00	1.57	3	*ip*	r	β	*rc*	19.45	13.00	1.23	97
62.	*M. koenigii*	*sp*	17.64 × 18.00	0.98	3	*ip*	r	ε	*rlmf*	15.65	16.00	0.98	100
63.	*M. oppositifolium*	*prsp*	29.97 × 27.00	1.11	1	*ip*	r	β	*pl*	27.00	25.65	1.97	100
64.	*D. quercifolia*	*sp*	14.11 × 13.70	1.03	3	*ip*	r	η	*sr*	12.45	12.70	2.00	100
65.	*A. virgata*	*obsp*	13.80 × 15.50	0.89	3	*hp*	r	ζ	*rc*	12.00	13.45	0.98	99
66.	*D. eracta*	*so*	18.63 × 23.00	0.81	3	*ip*	bl	η	*src*	16.00	21.05	1.65	100
67.	*L. camara*	*obsp*	17.21 × 18.50	0.93	4	*ip*	r	η	*pr*	16.53	17.50	1.32	100
68.	*V. officinalis*	*so*	19.44 × 24.00	0.81	3	*ip*	bl	η	*src*	17.20	23.00	1.95	100
69.	*A. zerumbet*	*sp*	21.45 × 16.50	1.03	1	*ip*	r	δ	*rc*	19.30	14.00	1.40	100
70.	*C. aromatica*	*obsp*	13.35 × 15.00	0.89	1	*hp*	r	ζ	*rc*	11.35	12.00	1.20	100

PS: Pollen shape (ob = Oblate, obsp = Oblate-spheroidal, pro = Prolate, prsp = Prolate spheroidal, sp = Spheroidal, so = Sub-oblate, spr = Sub-prolate); **P×E:** Polar axis × Equatorial diameter **P / E:** Polar axis / Equatorial diameter; **π:** Polarity (ap = Apolar, hp = Heteropolar, ip = Isopolar, pip = Para-isopolar); **Sym.:** Symmetry (bl = Bilateral, r = Radial); **Ap.:** Aperture (α = Colpate, β = Colporate, γ = Monolete, δ = Monoporate, ε = Pantoportae, ζ = Spheroidal, η = Tricolpate, θ = Tricolporate, ι = Tetracolporate, κ = Triporate, λ = Zonocolporate); **Ω:** Ornamentation (crc = Coarsely Reticulate, en = Echinate, fl = Fossulate, gl = Granulate, mrce = Metareticulate-echinate, mpr = Microperforate, men = Microechinate, mrc = Microreticulate, pr = Perforate, pl = Psilate, rlmf = Regulate microperforate, rc = Reticulate, sb = Scabrate, src = Semireticulate, sl = Spinulose, sr = Striate); **CL:** Colpus length; **CW:** Colpus width; **ET:** Exine thickness; **PV:** Pollen viability percentage; * Triangular in Polar view.

PS: Forma del polen (ob = Oblato, obsp = Oblato-esferoidal, pro = Prolato, prsp = Prolato esferoidal, sp = Esferoidal, so = Sub-oblato, spr = Sub-prolato); **P×E:** Eje polar × Diámetro ecuatorial **P / E:** Eje polar / Diámetro ecuatorial; **π:** Polaridad (ap = Apolar, hp = Heteropolar, ip = Isopolar, pip = Para-isopolar); **Sym.:** Simetria (bl = Bilateral, r = Radial); **Ap.:** Abertura (α = Colpado, β = Colporado, γ = Monolete, δ = Mono-porado, ε = Pantoporado, ζ = Esferoidal, η = Tri-colpado, θ = Tri-colporado, ι = Tetra-colporado, κ = Tri-porado, λ = Zonocolporado); Sym. : Simetria (bl = Bilateral, r = Radial); Ap.: Aberture (α = Colpado, β = Colporado, γ = Monolete, δ = Mono-porado, ε = Pantoporado, ζ = Esferoidal, η = Tri-colpado, θ = Tri-colporado, ι = Tetra-colporado, κ = Tri-porado, λ = Zonocolporado); **Ω:** Ornamentacion (crc = Reticulado grueso, en = Echinado, fl = Fosulado, gl = Granulado, mrce = Patrón reticular irregular-echinado, mpr = Microperforado, men = Microechinado, mrc = Microreticulado, pr = Perforado, pl = Psilado, rlmf = Rugulado microperforado, rc = Reticulado, sb = Scabrado, src = Semireticulado, sl = Spinulose, sr = Estriado); **CL:** Longitud del colpo; **CW:** Ancho del colpo; **ET:** Espesor de la exina; **PV:** Porcentaje de viabilidad polinica; * Vista polar ambito triangular.

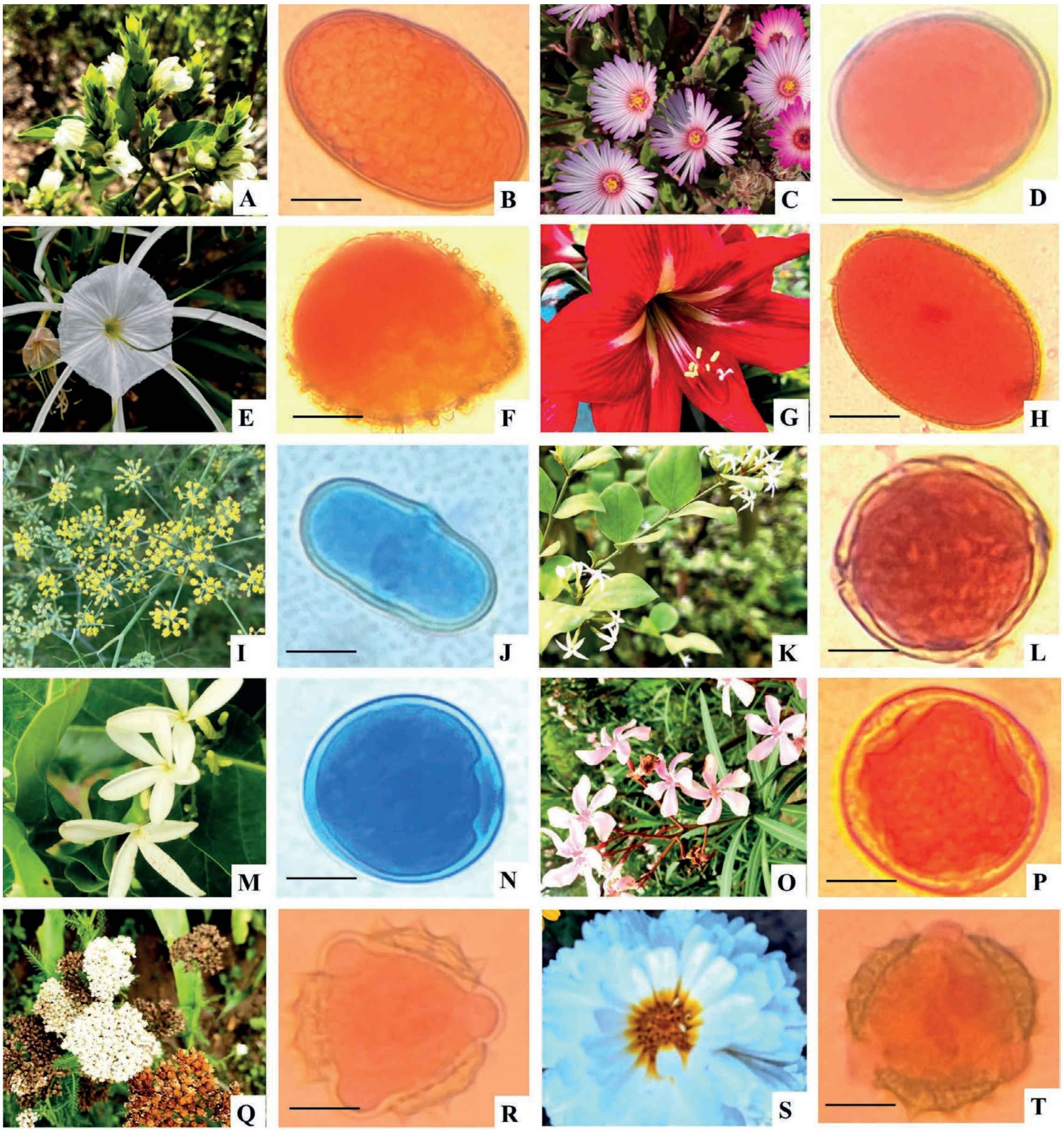

Fig. 4. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Justicia adhatoda*. C-D) *Cleretum bellideliform*. E-F) *Hymenocallis littoralis*. G-H) *Amaryllis belladonna*. I-J) *Foeniculum vulgare*. K-L) *Carissa spinarum*. M-N) *Holarrhena pubescens*. O-P) *Nerium oleander.* Q-R) *Achillea millefolium*. S-T) *Bellis perennis.* Scale: 10 µm.

Fig. 4. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Justicia adhatoda*. C-D) *Cleretum bellideliform*. E-F) *Hymenocallis littoralis*. G-H) *Amaryllis belladonna*. I-J) *Foeniculum vulgare*. K-L) *Carissa spinarum*. M-N) *Holarrhena pubescens*. O-P) *Nerium oleander*. Q-R) *Achillea millefolium*. S-T) *Bellis perennis*. Escala: 10 µm.

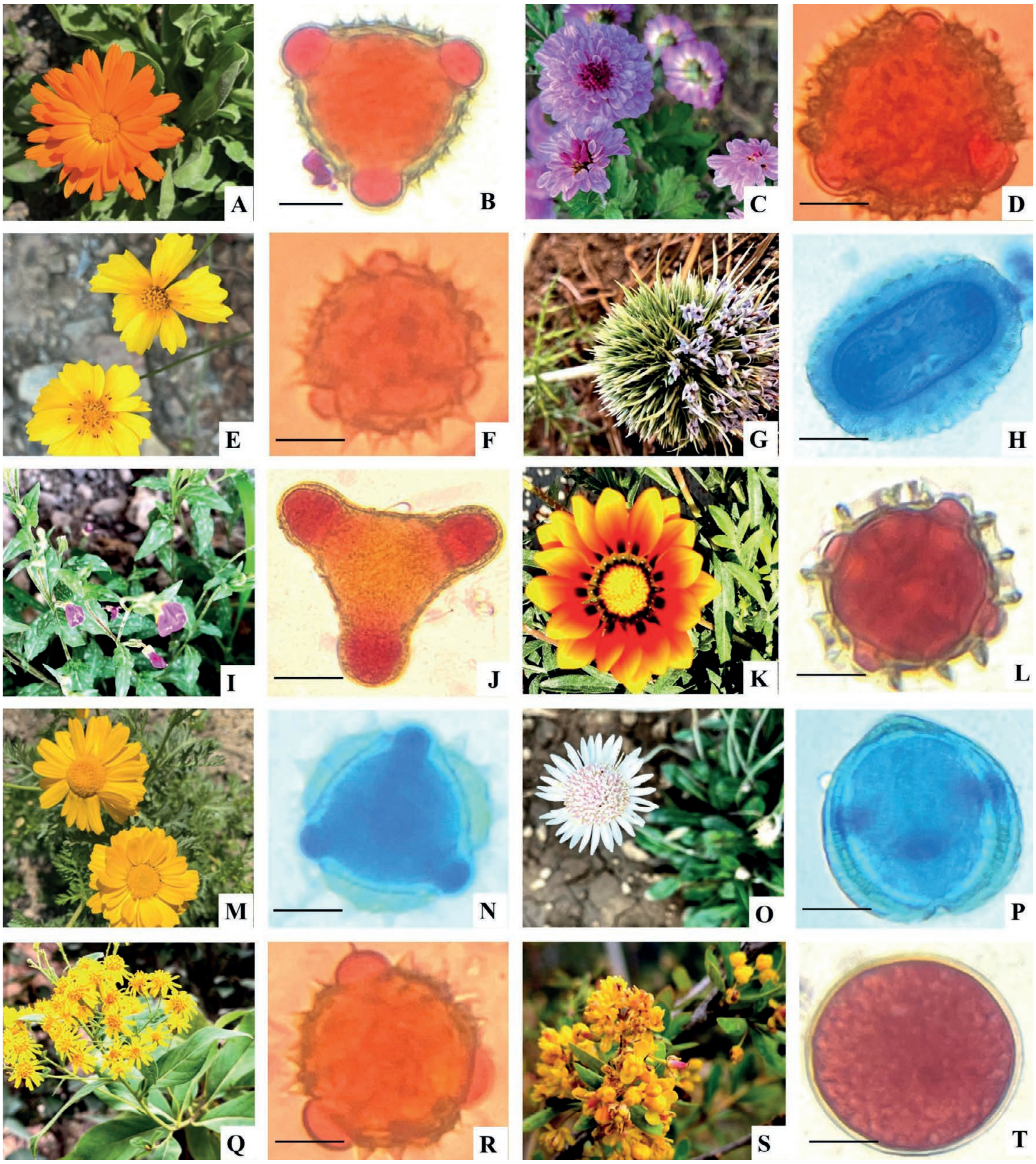

Fig. 5. Field photographs of studied taxa and their respective pollen grains under light microscopy: A-B) *Calendula officinalis*. C-D) *Chrysanthemum multiflora*. E-F) *Coreopsis lanceolata*. G-H) *Echinops echinatus.* I-J) *Emilia sonchifolia*. K-L) *Gazania rigens*. M-N) *Glebionis segetum*. O-P) *Hypochaeris sonchoides.* Q-R) *Jacobaea vulgaris*. S-T) *Berberis aristata.* Scale: 10 µm.

Fig. 5. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Calendula officinalis*. C-D) *Chrysanthemum multiflora*. E-F) *Coreopsis lanceolata*. G-H) *Echinops echinatus*. I-J) *Emilia sonchifolia*. K-L) *Gazania rigens*. M-N) *Glebionis segetum*. O-P) *Hypochaeris sonchoides*. Q-R) *Jacobaea vulgaris*. S-T) *Berberis aristata*. Escala: 10 µm.

With respect to life span, 61.4% perennial (P) species predominated, followed by 35.7% annuals (A), while biennials (B) contributed minimally 2.9% (Fig. 2B). Flowering months recorded with considerable variation, several taxa exhibited extended or bimodal flowering periods, which indicated ecological adaptability with broad reproductive period across seasonal gradients (Table 2). The anther lobe condition among the 70 studied taxa was evenly distributed, with 50% of the species exhibiting monolobed (*lb*) pollen morphology, whereas the remaining 50% displayed bilobed (*2lb*) morphology (Fig. 2C).

Pollen symmetry and polarity

Pollen grains of the recorded taxa exhibited notable variation in their polarity and symmetry (Fig. 2D-E). Most of plant species were observed with isopolar pollen (*ip* ≈ 71.4%), whereas apolar (*ap* ≈ 18.6%), heteropolar (*hp* ≈ 7.1%), and para-isopolar (*pip* ≈ 2.9%) conditions were also recorded among the studied pollen-taxa. In terms of symmetry, nearly 92.9% of the studied taxa were recorded with radially (*r*) symmetrical pollen grains, while only a small fraction (7.1%) exhibited bilateral (*bl*) symmetry.

Apertural configurations

A high degree of diversity in pollen apertures was observed, with 11 distinct aperture types identified across the studied taxa (Fig. 2F). The most frequent aperture type was tri-colpate (η ≈ 47.1%), which was followed by Colporate (β ≈ 11.4%), monoporate (δ), pantoporate (ε) and Spheroidal (ζ) types (each ≈ 7.1%), and tricolporate (θ ≈ 5.7%). Less frequent aperture types were Colpate (α) and Monosulcate (γ), each with ≈ 4.3%, and Tetracolporate (ι ≈ 2.9%). While rare forms were triporate (κ) and zonocolporate (λ), each with ≈ 1.4%. Notably, tricolporate (θ) apertures were well represented in Fabaceae, Lamiaceae, and Euphorbiaceae, while pantoporate (ε) grains were restricted to a taxa of Malvaceae (*Abelmoschus esculentus* L.) and Nyctaginaceae (*Mirabilis jalapa* L.).

Exine ornamentation patterns

The studied taxa displayed remarkable diversity in their pollen exine ornamentations (Fig. 2G). In total-of 16 distinct ornamentation types [i.e. Coarsely Reticulate (crc), Echinate (en), Fossulate (fl), Granulate (gl), Metareticulate-echinate (mrce), Microperforate (mpr), Microechinate (men), Microreticulate (mrc), Perforate (pr), Psilate (pl), Regulate microperforate (rlmf), Reticulate (rc), Scabrate (sb), Semireticulate (src), Spinulose (sl), and Striate (sr)] were identified.

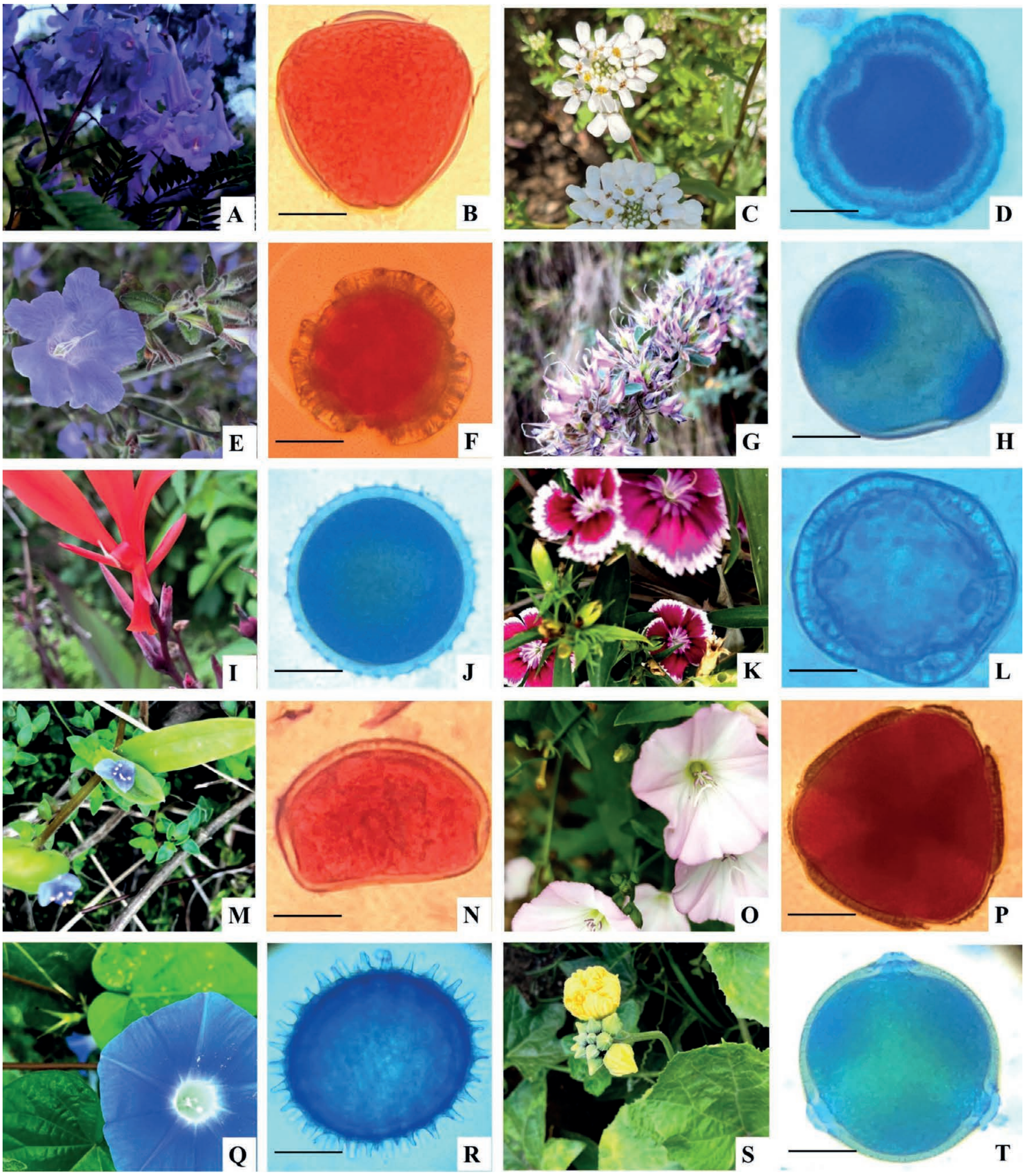

Fig. 6. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Jacaranda mimosifolia.* C-D) *Iberis sempervirens.* E-F) *Campanula portenschlagiana*. G-H) *Campanula macrostyla*. I-J) *Canna indica*. K-L) *Dianthus chinensis*. M-N) *Commelina cyanea*. O-P) *Convolvulus arvensis.* Q-R) *Ipomoea hederaceae*. S-T) *Luffa acutangula*. Scale: 10 µm.

Fig. 6. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Jacaranda mimosifolia*. C-D) *Iberis sempervirens*. E-F) *Campanula portenschlagiana*. G-H) *Campanula macrostyla*. I-J) *Canna indica*. K-L) *Dianthus chinensis*. M-N) *Commelina cyanea*. O-P) *Convolvulus arvensis*. Q-R) *Ipomoea hederaceae*. S-T) *Luffa acutangula*. Escala: 10 µm.

Among these, reticulate (rc) ornamentation was the most frequently encountered, occurring in approx. 42.9% of the species. This was followed by echinate (en ≈ 12.9%), psilate (pl) and scabrate (sb), each with ≈ 8.6%, and striate (sr ≈ 4.3%) ornamentation. Several other ornamentation forms were comparatively less common, including, coarsely reticulate (crc), fossulate (fl), microreticulate (mrc), perforate (pr), and semi-reticulate (src), each recorded in approx. 2.9 % of the studied taxa. A few highly specialized ornamentation patterns such as granulate (gl), metareticulate-echinate (mrce), microperforate (mpr), microechinate (men), regulate-microperforate (rlmf), and spinulose (sl) were each observed in about 1.4 % of the species.

Morphometric polar (P) and equatorial (E) pollen diameters

The pollen size recorded among the studied taxa showed substantial diversity, with both polar axis (P) and equatorial diameter (E) values spanning a wide range (Table 3; Fig. 3). The polar axis (P) ranged from 9.15 μm (lower outlier, *Earina autumnalis* G. Forst.) to 32.4 μm (upper outlier, *Foeniculum vulgare* Mill.), with an interquartile range (IQR) spanning 17.64 - 21.96 μm and a median value of 19.84 μm. The lower extreme (11.6 μm) and upper extreme (28.44 μm) indicate that most taxa fall within a moderately narrow size range, while a few species (including *F. vulgare*) namely: *Justicia adhatoda* L. (31.36 μm), *Amaryllis belladonna* L. (30.1 μm), *Myoporum oppositifolium* R. Br. (29.97 μm) represent size extremes. Similarly, the equatorial diameter (E) varied between 11 μm (lower extreme and outlier, *Hydrangea arborescens* L.) and 29.95 μm (upper extreme and outlier, *Convolvulus arvensis* L.), with a median of 20 μm and an IQR of 15.98 - 21.64 μm. Smallest ($P \times E = 9.15 \times 15.00$ μm) pollen grains were recorded in *E. autumnalis*, while largest ($P \times E = 30.10 \times 29.50$ μm) grains were observed in *A. belladonna*.

P/E ratio and derived pollen shapes

The P/E ratio recorded in the studied taxa, reflected a wide diversity of pollen shapes (Table 3; Fig. 2H). Highest P/E ratio (1.64) was recorded in *F. vulgare* (Prolate), while lowest P/E ratio (0.59) was present in *Emilia sonchifolia* L. (Oblate). P/E ratio revealed seven distinct pollen shapes i.e. oblate, oblate-spheroidal, prolate, prolate-spheroidal, spheroidal, sub-oblate, and sub-prolate were identified (Fig. 2H). Among these, spheroidal (*sp* ≈ 42.8%) forms were the most common, followed by prolate-spheroidal (*prsp* ≈ 18.6%), oblate-spheroidal (*obsp* ≈ 14.3%), prolate (*pro* ≈ 8%), sub-oblate (*so* ≈ 7.1%), sub-prolate (*spr* ≈ 6%), and oblate (*ob* ≈ 2.9%).

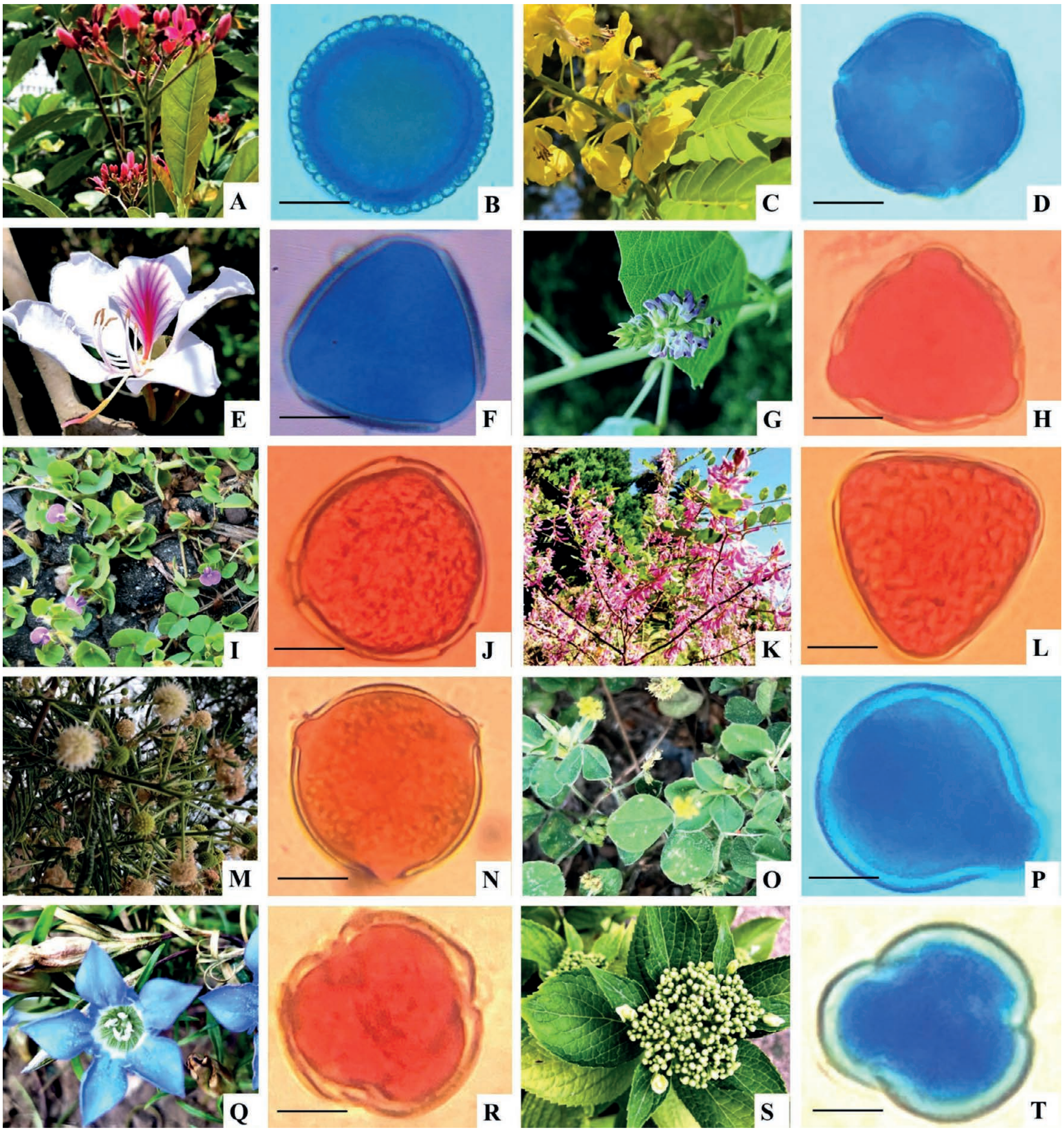

Fig. 7. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Jatropha integerrima*. C-D) *Biancaea decapetala*. E-F) *Bauhinia variegata*. G-H) *Cullen corylifolium*. I-J) *Desmodium triflorum*. K-L) *Indigofera tinctoria*. M-N) *Leucaena leucocephala*. O-P) *Medicago lupine*. Q-R) *Gentiana kurroo*. S-T) *Hydrangea arborescens*. Scale: 10 μm.

Fig. 7. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Jatropha integerrima*. C-D) *Biancaea decapetala*. E-F) *Bauhinia variegata*. G-H) *Cullen corylifolium*. I-J) *Desmodium triflorum*. K-L) *Indigofera tinctoria*. M-N) *Leucaena leucocephala*. O-P) *Medicago lupina*. Q-R) *Gentiana kurroo*. S-T) *Hydrangea arborescens*. Escala: 10 μm.

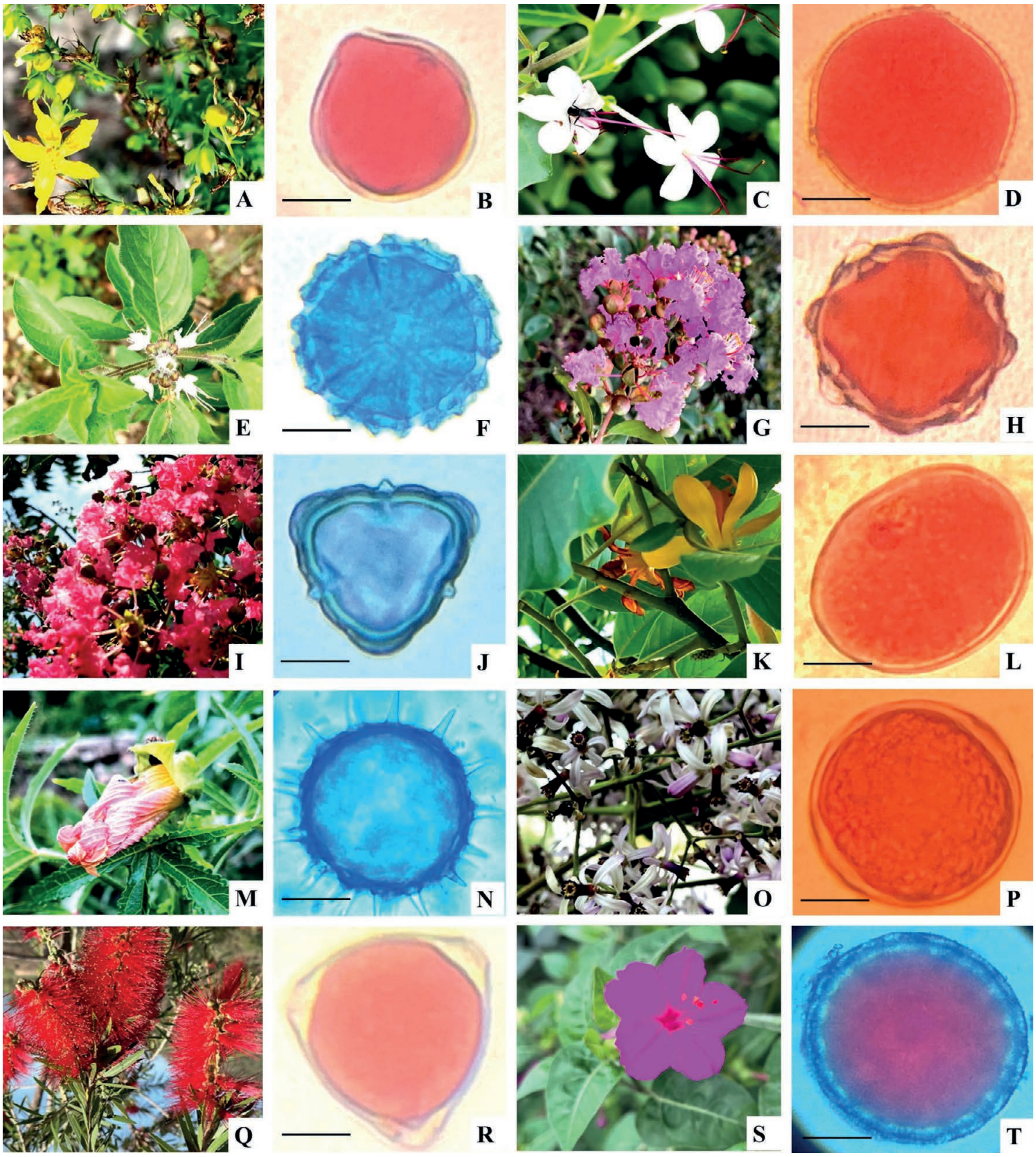

Fig. 8. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Hypericum triquetrifolium*. C-D) *Clerodendrum in*erme. E-F) *Ocimum basilicum*. G-H) *Lagersroemia indica*. I-J) *Lagerstroemia speciosa*. K-L) *Magnolia champaca*. M-N) *Abelmoschus esculentus*. O-P) *Melia azedarach*. Q-R) *Callistemon citrinus*, S-T) *Mirabilis jalapa*. Scale: 10 µm.

Fig. 8. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Hypericum triquetrifolium*. C-D) *Clerodendrum inerme*. E-F) *Ocimum basilicum*. G-H) *Lagerstroemia indica*. I-J) *Lagerstroemia speciosa*. K-L) *Magnolia champaca*. M-N) *Abelmoschus esculentus*. O-P) *Melia azedarach*. Q-R) *Callistemon citrinus*. S-T) *Mirabilis jalapa*. Escala: 10 µm.

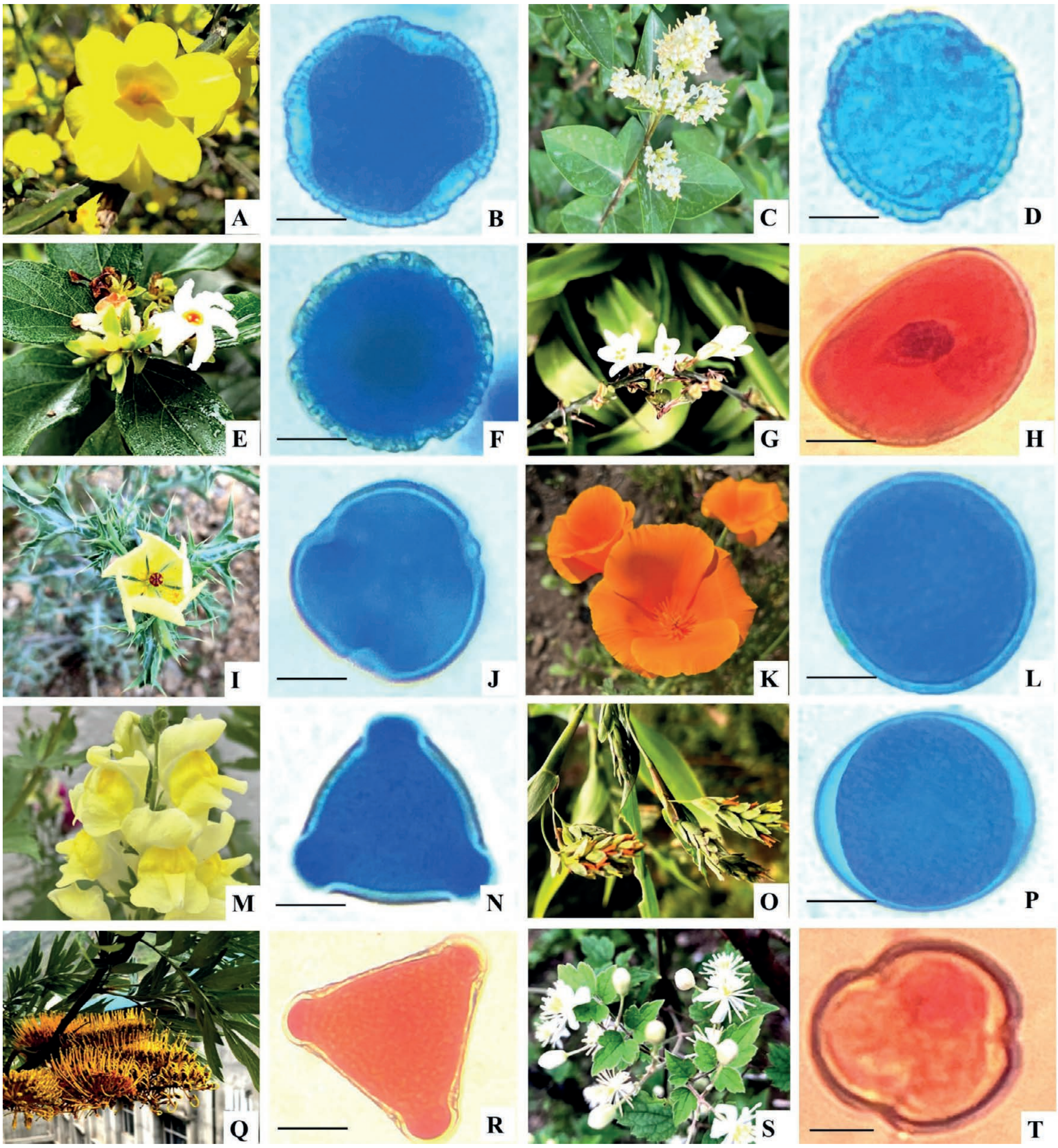

Fig. 9. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Jasminium nudiflorum*. C-D) *Ligustrum japonicum*. E-F) *Nyctanthes arbor-tristis*. G-H) *Earina autumnalis*. I-J) *Argemone mexicana*. K-L) *Eschscholzia californica*. M-N) *Antirrhinum majus*. O-P) *Coix lacryma-jobi.* Q-R) *Grevillea robusta*. S-T) *Clematis apiifolia.* Scale: 10 µm.

Fig. 9. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Jasminum nudiflorum*. C-D) *Ligustrum japonicum*. E-F) *Nyctanthes arbor-tristis*. G-H) *Earina autumnalis*. I-J) *Argemone mexicana*. K-L) *Eschscholzia californica*. M-N) *Antirrhinum majus*. O-P) *Coix lacryma-jobi*. Q-R) *Grevillea robusta*. S-T) *Clematis apiifolia*. Escala: 10 µm.

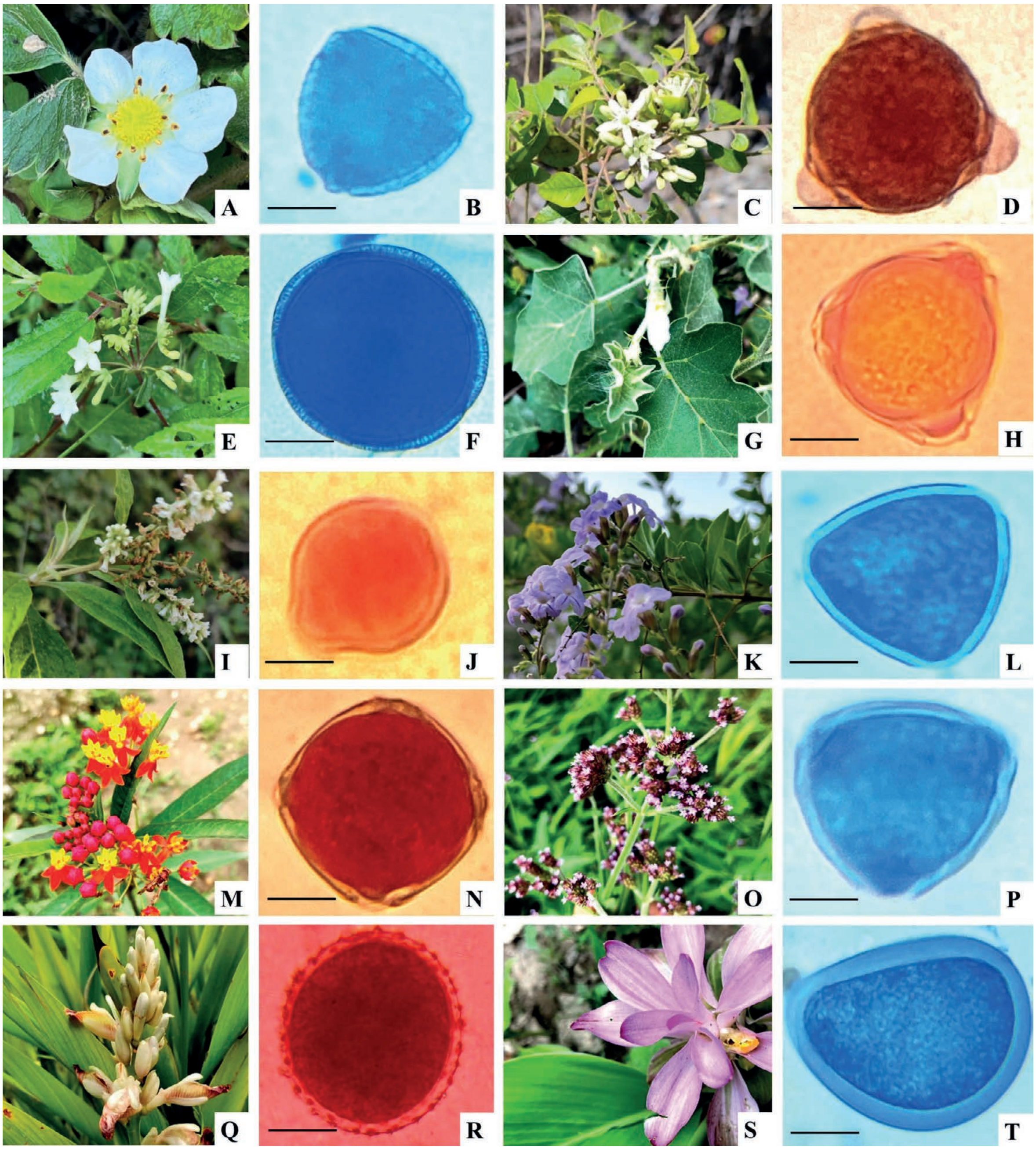

Fig. 10. Field photographs of the studied taxa and their respective pollen grains under light microscopy: A-B) *Fragaria chiloensis*. C-D) *Murraya koenigii*. E-F) *Myoporum oppositifolium*. G-H) *Datura quercifolia*. I-J) *Aloysia virgata*. K-L) *Duranta erecta*. M-N) *Lantana camara*. O-P) *Verbena officinalis*. Q-R) *Alpinia zerumbet*. S-T) *Curcuma aromatica*. Scale: 10 µm.

Fig. 10. Fotografías de campo de los taxones estudiados y sus respectivos granos de polen bajo microscopía óptica: A-B) *Fragaria chiloensis*. C-D) *Murraya koenigii*. E-F) *Myoporum oppositifolium*. G-H) *Datura quercifolia*. I-J) *Aloysia virgata*. K-L) *Duranta erecta*. M-N) *Lantana camara*. O-P) *Verbena officinalis*. Q-R) *Alpinia zerumbet*. S-T) *Curcuma aromatica*. Escala: 10 µm.

Apertural dimensions and exine thickness

Apertural measurements and exine thickness exhibited considerable variation across the studied taxa (Table 3; Fig. 3). The number of colpi ranged from one (recorded in 24 taxa) to eight (in one taxa: *Lagersroemia indica* L.). The colpus length measured ranged from 8.3 μm (lower outlier, *E. autumnalis*) to 27 μm (upper outlier and extreme, *M. oppositifolium*), with a median value of 17.6 μm and an IQR of 16 - 20.7 μm; the lower extreme was recorded at 8.95 μm. Similarly, colpus width recorded ranged from 3.97 μm (lower outlier) to 27 μm (upper outlier and extreme), with a median of 17.9 μm and an IQR of 13.72 -19.50 μm; the lower extreme was 5.03 μm. Exine thickness (ET) exhibited comparatively lower variability as reflected in the box-plot distribution (Fig. 3). Thickness ranged from 0.83 μm (lower extreme and outlier, *Cleretum bellideliform* Burm. F.) to 2.85 μm (upper outlier, *L. speciosa*), with a median of 1.08 μm and an IQR of 0.98 -1.4 μm; the upper extreme was recorded at 2.02 μm. Few species (including *Lagerstroemia speciosa* L.), namely, *Iberis sempervirens* L. (ET=2.8), *Melia azedarach* L. and *Coix lacryma-jobi* L. (each with ET = 2.6) exhibited markedly thicker exines extending beyond the upper quartile range.

Pollen viability across the studied species

Pollen viability (PV) was consistently high across the studied taxa, indicating strong reproductive potential (Table 3). Nearly 39 species exhibited complete viability (100%), while the majority of the taxa showed consistently high viability levels exceeding 90%, indicating strong reproductive vigor across the studied plants. Only one taxon, *F. vulgare*, showed slightly lower *PV* (84%). While, several other species e.g. *Coreopsis lanceolata* L., *Dianthus chinensis* L., *Fragaria chiloensis* Mill., *I. sempervirens*, *Biancaea decapetala* Roth., *Aloysia virgata* Juss., *C. apiifolia*, *C. arvensis*, *Commellina cyanea* R. Br., and *Magnolia champaca* L. were recorded with very high viability values exceeding 97%.

DISCUSSION

The present study shows that the angiosperm flora of district Sirmaur maintains a clear yet diverse pattern of pollen morphology, as revealed through a light microscopic dataset. Despite the wide taxonomic range, several traits remain consistent across taxa. At the same time, some features vary noticeably. This suggests that pollen characters are shaped by both evolutionary stability and ecological adaptation. The dominance of herbaceous and perennial life forms, along with extended or bimodal flowering periods (Fig. 2A-B; Table-2), indicates prolonged reproductive activity.

Such a pattern is likely advantageous in Himalayan environments where seasonal conditions are highly variable.

Most taxa produced radially symmetrical and isopolar pollen grains (Fig. 2D-E). These traits are commonly linked with generalized pollination systems. Similar observations have been reported earlier (Jamwal, 2021). However, a few species showed bilateral symmetry and heteropolarity. These deviations are not random. They likely reflect more specialized pollination strategies, as suggested by Siraw (2022). Within the context of the present dataset, this indicates that even a predominantly conserved pollen structure can accommodate localized adaptive shifts.

Apertural diversity follows a similar trend (Fig. 2F). Tri-colpate and colporate pollen types are widespread and appear to be evolutionarily stable. This agrees with earlier regional studies (Jamwal, 2021; Chaya & Kumar, 2025). While, less common aperture types, such as pantoporate and zonocolporate forms, occur only in a few taxa. These may represent functional adjustments under specific ecological conditions. Their presence within the dataset highlights the importance of including a broad taxonomic range when assessing pollen diversity.

Exine ornamentation also shows a clear gradient (Fig. 2G). Reticulate patterns are the most common and appear to be structurally efficient. On the other hand, echinate, spinulose, and granulate types indicate higher levels of specialization. These surface features are known to influence pollen adhesion and interaction with pollinators (Rauf & Perveen, 2024; Huang *et al*., 2023). The variation observed across the studied taxa suggests that exine architecture is closely linked to pollination ecology, even when assessed using light microscopy.

Morphometric traits further support this interpretation. Most pollen grains fall within a moderate size range (Fig. 3), suggesting the presence of an optimal size window for effective dispersal and deposition. However, a few taxa show extreme values, which likely reflect species-specific adaptations. Variation in P/E ratio and pollen shape also indicates differences in pollen geometry (Table 3, Fig 3), which may influence transport efficiency and pollinator interaction. These patterns reinforce the value of morphometric parameters in interpreting pollen diversity within a dataset-based framework.

Apertural dimensions show interesting variation (Table 3; Fig 3). Colpus width is more variable than colpus length, suggesting that aperture breadth may play a more active role in hydration and germination processes. In contrast, exine thickness remains relatively stable across most taxa. This indicates strong structural constraints. In a few cases, thicker exine layers were observed. These may represent adaptive responses to environmental stress, particularly desiccation and increased UV exposure in Himalayan conditions.

Pollen viability remained consistently high across most taxa (Table 3). This suggests that the observed morphological diversity does not compromise reproductive efficiency. Similar patterns have been reported earlier (Pratignya *et al*., 2022). High viability across the dataset indicates that these taxa are well adapted to local environmental conditions. It also supports the idea that structural variation in pollen can occur without affecting functional performance.

The present dataset highlights the dual significance of pollen morphology. It serves both as a taxonomic tool and as an indicator of ecological adaptation. The integration of qualitative traits with morphometric parameters provides a more complete understanding of angiosperm pollen diversity in the north-western Himalayan region. Importantly, this study contributes baseline data for district Sirmaur, a region that remains underrepresented in palynological research.

CONCLUSION

The palynological study presented here is significant for advancing our understanding of angiosperm pollen diversity in the north-western Himalayan region. The observed variation in pollen traits, including shape, symmetry, aperture type, ornamentation, and polarity, provides valuable taxonomic insights and reflects ecological adaptation and pollination strategies. The predominance of spheroidal and prolate-spheroidal pollen forms, along with tri-colpate apertures and reticulate ornamentation, supports patterns commonly associated with insect-mediated pollination. At the same time, consistently high pollen viability indicates strong reproductive efficiency under prevailing environmental conditions. Variation in aperture types and polarity further suggests underlying evolutionary differentiation among taxa. This light microscopic dataset serves as a useful reference for future taxonomic, ecological, and palaeopalynological studies, and highlights the broader significance of pollen morphology in understanding vegetation dynamics and evolutionary trends in the north-western Himalayan region, particularly in Sirmaur, Himachal Pradesh.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

Chaya, P. & Kumar, M. J. (2025). Pollen characterization of some tropical flora of Kollapur revenue division of Nagarkurnool district of Telangana State, South India. *Annals of Plant Sciences* 14 (5): 6832-6840. https://doi.org/ 10.5281/zenodo.15578776

Chowdhery, H. J. & Wadhwa, B. M. (1984a). *Flora of Himachal Pradesh: Analysis*. Vol. 1. New Delhi: Botanical Survey of India.

Chowdhery H. J. & Wadhwa, B. M. (1984b). *Flora of Himachal Pradesh: Analysis*. Vol. 2. New Delhi: Botanical Survey of India.

Devi, A. & Mattu, V. K. (2017). Preparation of floral calendar of honey plants of Kangra and adjoining areas of Himachal Pradesh. *International Journal of Science and Research* 6 (2): 371-378.

Dwarka, S. G., Ghugal, N. C., Panday, A. K. & Tripathi, S. K. (2025). Foraging behaviour of honeybee in Niger (*Guizotia abyssinica* (L.f.) Cass.): A review. *Journal of Biology and Nature* 17 (1): 102-111. https://doi.org/10.56557/joban/2025/v17i19236

Effiom, A. C., Neumann, F. H., Scott, L. & Bamford, M. K. (2025). Morphology and ecological significance of Holocene palynomorphs from the Indian Ocean coastal belt biome of South Africa. *Palynology* 49 (3): 2428382. https://doi.org/10.1080/01916122.2024.2428382

Erdtman, G. (1952). Pollen morphology and plant taxonomy. *Geologiska Föreningen i Stockholm Förhandlingar*, 74 (4): 526-527. https://doi.org/10.1080/11035895209453507

Erdtman, G. (1960). The acetolysis method: A revised description. *Svensk Botanisk Tidskrift* 54: 561-564.

Fyfe, R. M., Edwards, K. J. & Scoble, L. (2025). Palynology, landscape and land use: Retrospect, prospect and research agendas. *Journal of Archaeological Science* 179: 106233. https://doi.org/10.1016/j.jas.2025.106233

Gill, M. C. & Walters K. F. A. (2022). Potential use of floral nectar sugar characteristics in plant selection for pollinator habitats. *Journal of Apicultural Research* 62 (2): 266-273. https://doi.org/10.1080/00218839.2022.2081443

Halbritter, H., Ulrich, S., Grímsson, F., Weber, M., Zetter, R., Hesse, M., Buchner, R., Svojtka, M. & Frosch-Radivo, A. (2018). *Illustrated pollen Terminology*. (2° Ed). Springer International Publishing. https://doi.org/10.1007/978-3-319-71365-6

Hooker, J. D. (1875–1897). *The flora of British India.* Vols 1-7. London: L. Reeve. https://doi.org/10.5962/bhl.title.678

Huang, X., Wu, R., Xiong, Z. & Ma, Z. (2023). Pollen morphology of *Clerodendrum* L. (Lamiaceae) from China and its systematic implications. *PhytoKeys* 235: 53-68. https://doi.org/10.3897/phytokeys.235.111516

Ige, O. E. & Essien, B. C. (2021). The role of non-pollen palynomorphs in Quaternary palaeoecological study of Akoko environment, Ondo State, Nigeria. *International Journal of Innovative Agriculture and Biology Research* 9 (1): 1-10.

Iravani, S. & Varma, R. S. (2021). Plant pollen grains: A move towards green drug and vaccine delivery. *Journal of Pharmacological Sciences* 545: 286-294. https://doi.org/10.1007/s40820-021-00654-y

Jamwal, R. (2021). Pollen morphology of some selected bee floral resources of *Apis cerana* F. and *Apis mellifera* L. using scanning electron microscopy from Himachal Pradesh, India. *Uttar Pradesh Journal of Zoology* 42 (17): 8-16.

Javed, M., Prasad, N., Farooqui, A., Quamar, M. F. & Singh M. (2024). Taxonomic insights into medicinal plants pollen using advanced microscopy techniques from the Western Ghats, India. *Grana* 63 (4): 275-288. https://doi.org/10.1080/00173134.2024.2391515

Kaur, H. & Sharma, M. (2004). *Flora of Sirmaur (Himachal Pradesh)*. Dehradun: Bishen Singh Mahendra Pal Singh.

Kaur, H., Sharma, S. K. & Sharma, P. C. (2019). Palynological study of pollens of some important bee floral plants in Kangra district of Himachal Pradesh. *Himachal Journal of Agricultural Research* 45: 66-75. https://doi.org/10.11609/jott.8647.15.12.24402-24408

Khaiwal, R., Goyal, A., Kumar, S., Aggarwal, A. & Mor, S. (2021). Pollen calendar to depict seasonal periodicities of airborne pollen species in a city situated in Indo-Gangetic plain, India. *Atmospheric Environment* 262: 118649. https://doi.org/10.1016/j.atmosenv.2021.118649

Kremp, G. O. W. (1965). *Morphologic encyclopaedia of palynology*. Tucson: University of Arizona Press, 185 pp.

Kumar, B., Singh, K., Kumar, P., Batool, Z., Dhiman, S. K. & Gairola, S. (2022). Palynological diversity of highly medicinal rare, endangered, and threatened plants from Western Himalaya, India. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 50 (3): 12787. https://doi.org/10.15835/nbha50312787

Lun, H. N. & Yang, C. F. (2025). Quantitative analyses reveal interactions of community plants and insect flower visitors associated with nectar amino acids. *Plant Ecology* 226: 451-463. https://doi.org/10.1007/s11258-025-01506-0

Makra, L., Coviello, L., Gobbi, A., Jurman, G., Furlanello, C., Brunato, M., Ziska, L. H., Hess, J. J., Damialis, A., Plaza Garcia, M. P., Tusnády, G., Czibolya, L., Ihász, I., Deák, Á. J., Mikó, E., Dorner, Z., Harry, S. K., Bruffaerts, N., Packeu, A., ... Traidl-Hoffmann, C. (2024). Forecasting daily total pollen concentrations on a global scale. *Allergy* 79: 2173-2185. https://doi.org/10.1111/all.16227

Mark, G. F. (1954). An aceto-carmine glycerol jelly for use in pollen-fertility counts. *Stain Technology* 29 (5): 277. https://doi.org/10.3109/10520295409115483

Mudavath, C. N., Kailas, J. G., Sugali, S., Ravula, D., Hari, R. & Boyina, R. P. R. (2016). The non-arboreal diversity of the Andaman Islands based on pollen analysis. *Palynology* 41 (4): 441-461. https://doi.org/10.1080/01916122.2016.1257517

Nair, P. K. K. (1991). Pollen morphology, plant taxonomy and evolution. *Rheedea* 1: 78-83. https://doi.org/10.22244/rheedea.1991.01.1-2.13

Parul, K. 2021. Pollen calendar: Tracking airborne pollen to prevent allergy. *The Indian Express*, September 8.

Pham-Thi, N. & Demoly, P. (2025). Pollen allergy and climate change: Perceptions by physicians and patients. *Exploration of Asthma and Allergy* 3: 100986. https://doi.org/10.37349/eaa.2025.100986

Pratignya, S., Ganneshwar, S., Manjusha, T., Saisravya, T., Umarani, K. & Rajesh, D. (2022). Pollen diversity of Sri Ram Narayan Khedia government degree college Banswada, Telangana State, India. *International Journal of Scientific Research in Science Engineering and Technology* 9 (4): 104-111. https://doi.org/10.32628/IJSRSET229419

Quamar, M. F. & Stivrins, N. (2021). Modern pollen and non-pollen palynomorphs along an altitudinal transect in Jammu and Kashmir, India. *Palynology* 45 (4): 669-684. https://doi.org/10.1080/01916122.2021.1915402

Quamar, M. F., Ali, S. N., Pandita, S. K. & Singh, Y. (2017). Modern pollen rain from Udhampur, India. *Palynology* 42 (1): 55-65. https://doi.org/10.1080/01916122.2017.1306811

Quamar, M. F., Singh, P., Garg, A., Tripathi, S., Farooqui, A., Shukla, A. N. & Prasad, N. (2022). Pollen characters and their evolutionary significance using light and confocal microscopy. *Palynology* 46 (4): 1-13. https://doi.org/10.1080/01916122.2022.2070294

Ragho, K. S. (2020). Role of pollen morphology in taxonomy and detection of adulterations in crude drugs. *Journal of Plant Science and Phytopathology* 4 (1): 24-27. https://doi.org/10.29328/journal.jpsp.1001046

Rauf, T. & Perveen, A. (2024). Palynological investigations of tribe Coreopsideae (Asteraceae) from Pakistan and Kashmir. *Pakistan Journal of Botany* 56 (2): 567-575. https://doi.org/10.30848/PJB2024-2(15)

Saklani, S. & Mattu, V. K. (2020). SEM study on pollens of bee floral resources from Kangra Hills. *International Journal of Biotech Trends and Technology* 10 (1): 67–71. https://doi.org/10.14445/22490183/IJBTT-V10I1P611

Saklani, S., Jamwal, R. & Mattu, V. K. (2018). SEM study on pollens from Hamirpur Hills. *Journal of Experimental Biology and Agricultural Sciences* 6 (6): 1004-1009. https://doi.org/10.18006/2018.6(6).1004.1009

Sarkar, S. & Prasad, V. (2002). *Ocimum* pollen grains from the Subathu formation, Himachal Pradesh. *Journal of Palaeosciences* 5: 165-167. https://doi.org/10.54991/jop.2002.1746

Saxena, R. K. & Bhattacharyya, A. P. (1986). Palynology of the Siwalik sediments of Kala Amb–Nahan area, Himachal Pradesh. *Palaeobotanist* 35 (2): 187-195. https://doi.org/10.54991/jop.1986.1528

Sharma, V. K., Goswami, M., Sharma, S. D. & Attri, K. (2021). Pollen viability and germination in low chill peach cultivars. *Biological Forum* 13 (1): 746-750.

Singh, N., Rana, K., Sharma, H. K., Thakur, M. & Thakur, R. K. (2017). Palynological studies of *Bombus haemorrhoidalis*. *International Journal of Current Microbiology Sciences* 6 (9): 2590-2602. https://doi.org/10.20546/ijcmas.2017.609.319

Siraw, V. P. (2022). A study on pollen irrigated parts of Ganganagar. *Journal of Phytological Research* 35 (2): 151-154.

Trivedi, A., Morthekai, P., Shukla, A., Nag, A. & Singh, D. S. (2023). Recent pollen spectra from Shimla catchment sanctuary. *Journal of the Palaeontological Society of India* 68 (2): 217-229. https://doi.org/10.1177/05529360231205149

Tsymbalyuk, Z. M., Ivanova, D. & Nitsenko, L. M. (2024). Taxonomic significance of pollen morphology of African *Oreobliton*. *South African Journal of Botany* 169: 134-145. https://doi.org/10.1016/j.sajb.2024.04.017

Wu, D., Liang, Y., Pei, Y., Li, B. & Liang, H. (2020). Plant exine capsules-based encapsulation strategy. *Food Research International* 127: 108691. https://doi.org/10.1016/j.foodres.2019.108691

Xie, S., Li, K., Li, F., Yang, X. & Reitalu, T. (2024). Modern pollen–plant diversity relationships. *Ecological Indicators* 167: 112739. https://doi.org/10.1016/j.ecolind.2024.112739